



BIOMORPHIC EXPLORERS

BIOMORPHIC EXPLORERS

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**DARPA WORKSHOP on Biologically Inspired Approaches for MAV's
April 21-22, 1999, Alexandria, VA**

BIOMORPHIC EXPLORERS

BIOMORPHIC EXPLORERS

- **SMALL, DEDICATED, LOW-COST EXPLORERS
THAT CAPTURE SOME OF THE KEY
FEATURES OF BIOLOGICAL EXPLORERS**
- **CONDUCTED WORKSHOP, AUG 19-20, 1998**
 - **SPONSORED BY NASA/JPL**
 - **VERY SUCCESSFUL; OVER 150
PARTICIPANTS**

BIOMORPHIC EXPLORERS

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OPENING REMARKS FIRST NASA/JPL WORKSHOP ON BIOMORPHIC EXPLORERS FOR FUTURE MISSIONS

Dr. Peter B. Ulrich

- “The fiscal and physics constraints we face will, in Darwinian fashion, lead us to do what nature does so well...economize and minimize. Emerging from that vision, the Biomorph Explorer will be an economic and minimalist marvel that captures the best that nature has to offer”

Biomorphic Explorers: Classification (Based on Mobility and Ambient Environment)

Biomorphic Explorers

Aerial Surface/Subsurface



Seed Wing



Honey Bee



Humming Bird



Soaring Bird



Ant



Centipede



Snake



Earthworm



Jelly Fish



Germinating Seed

Biomorphic Surface Systems

Biomorphic Subsurface Systems

Examples of biological systems that serve as inspiration for designing the biomorphic explorers in each class

Biomorphic Explorers: Classification (Based on Mobility and Ambient Environment)

Biomorphic Explorers

Surface/Subsurface

Aerial



Biomorphic Surface Systems

Biomorphic Subsurface Systems



Seed Wing Flyer (60 g)



Ornithopter



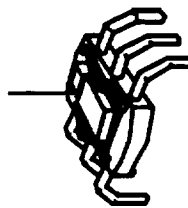
Glider (75 g)



Powered Flyer



Reconfigurable
Legs/Foot



Hexapod
(1-2 kg)



Artificial Jelly Fish



Artificial Earthworm

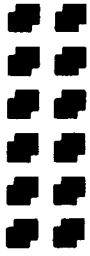


Worm Robot (85 g)

Candidate biomorphic explorers on the drawing board, with mass of design under study in 1998 in parentheses

BIOMORPHIC EXPLORERS

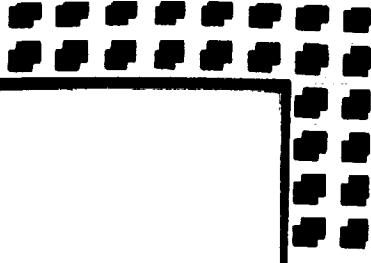
- **KEY FEATURES**
 - **VERSATILE MOBILITY: aerial, surface, subsurface, and in fluids**
 - **ADAPTIVE, DISTRIBUTED OPERATION**
 - **BIOMORPHIC COMMUNICATIONS**
 - **BIOMORPHIC SENSOR FUSION**
 - **BIOMORPHIC COOPERATIVE BEHAVIOR**



BIOMORPHIC EXPLORERS

Biomorphic Flight Systems: Vision

- Extended reach over all kinds of terrain
- Unique perspective for imaging and Spectral Signature
- Many flyers work in cooperation with larger aircraft, and balloons to enable new missions to reach currently inaccessible locations



BIOMORPHIC EXPLORERS
BIOMORPHIC FLIGHT SYSTEMS



TOTAL MASS: 57 g →
PAYLOAD MASS: 48 g

a. Seed Wing Pod



b. Seed Wing Pod Flyer



← TOTAL MASS: 57 g
PAYLOAD MASS: 32 g

c. Biomorph Glider



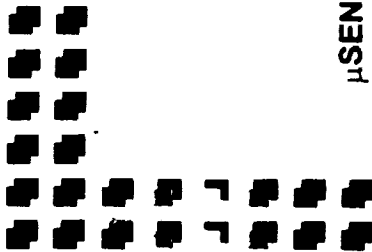
TOTAL MASS: 57 g →
PAYLOAD MASS: 6 g

d. Biomorph Flyer

Biomorphic flight systems offer rapid mobility and extended reach. For comparison the above illustrates for the same total mass of the system, the respective payload fractions in each case

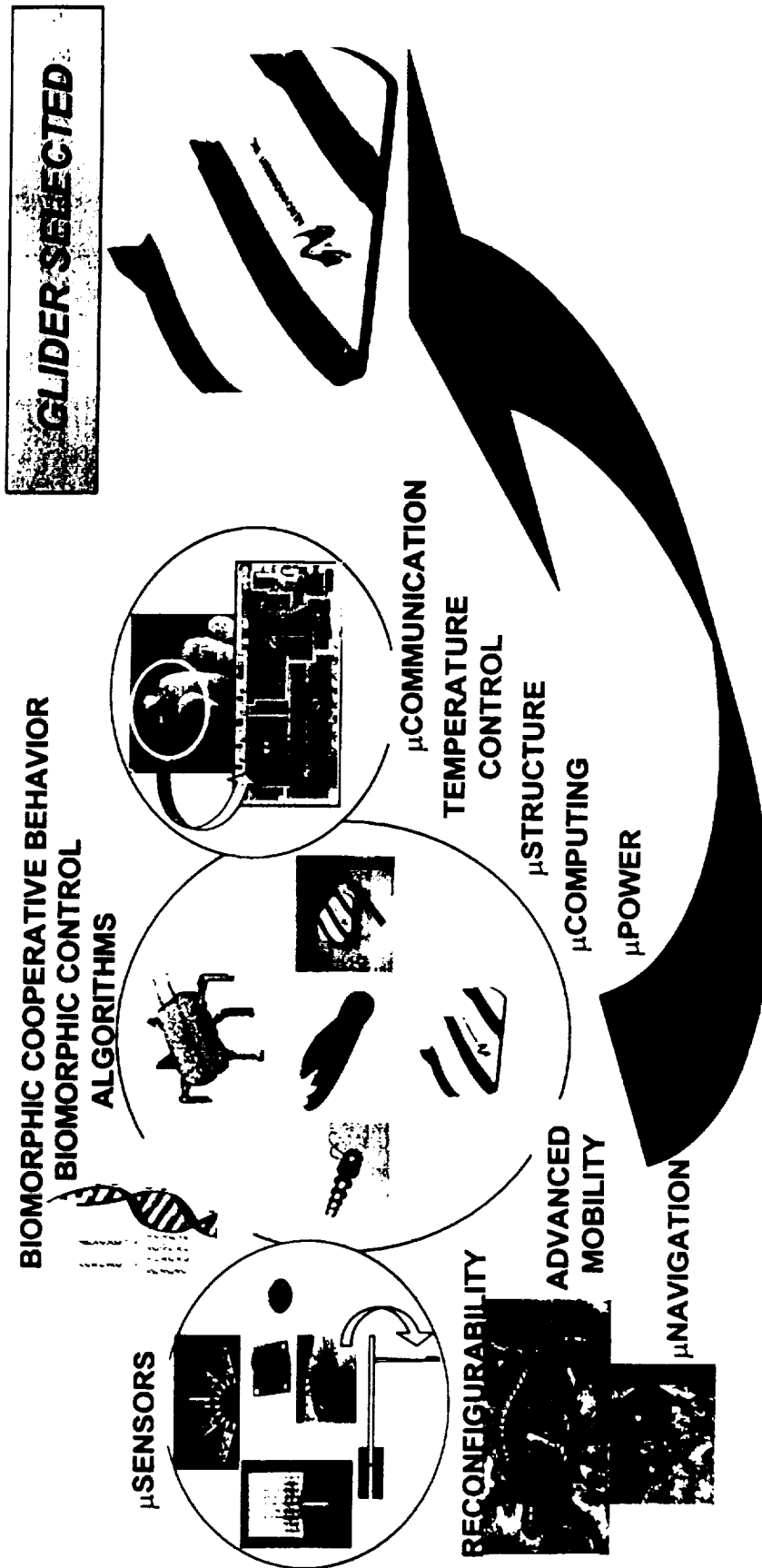
BIOMORPHIC EXPLORERS

- **PAYOFF**
- **BIOMORPHIC EXPLORERS, IN COOPERATION WITH
CURRENT EXPLORATION PLATFORMS CAN
ENABLE**
 - **EXPLORATION OF CURRENTLY
INACCESSIBLE AND/OR HAZARDOUS
LOCATIONS**
 - **MUCH BROADER COVERAGE OF
EXPLORATION SITES**
 - **EXPLORATION AT LOWER COST**



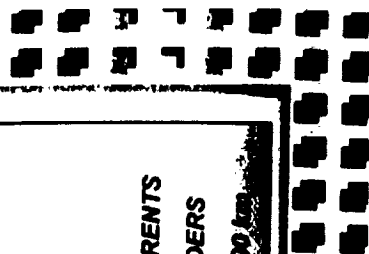
BIOMORPHIC EXPLORERS

Biomorphic Explorer: Conceptual Design



SELECTION CRITERIA	
•	LOW MASS/VOLUME
•	HIGH PAYLOAD FRACTION
•	LARGE RANGE OF MOBILITY
•	ACTIVE CONTROL
•	IMPLEMENTATION READINESS

GLIDER BASELINE DESIGN CHARACTERISTICS	
•	MASS: 75 g
•	PAYLOAD FRACTION: 60 %
•	GLIDE RATIO, L/D ~ 5.8
•	LARGE RANGE OF AERIAL MOBILITY: ~ 50 km to 100 km
•	LEVERAGE FROM NAV TECHNOLOGY
•	VOLUME: 300 cm ³
•	ACTIVE FLIGHT CONTROL
•	SOLAR NAVIGATION
•	SOARING FLIGHT IN RISING CURRENTS
•	COOPERATIVE MISSION: 32 GLIDERS
•	COVERAGE AREA: ~ 100 km x 100 km



Biomorphic Gliders

- Small, simple, low-cost system ideal for distributed measurements, reconnaissance and wide-area dispersion of sensors and small experiments.
- Payload mass fraction 50% or higher.
- small mass (100 g - 500 g)
- low radar cross section
- larger numbers for given payload due to low mass
- amenable to cooperative behaviors
- missions use potential energy: deploy from existing craft at high altitude
- Captures features of soaring birds, utilizing rising currents in the environment
- *Adaptive Behavior*
- *Self Repair features*



Biomorphic Gliders

- Small, simple, low-cost system ideal for reconnaissance and wide-area dispersion of sensors and small experiments.
- Payload mass fraction 50% or higher.



	Baseline				
Total Mass (M)	=	57	75	250	500 g
Payload (P)	=	32	45	150	300 g
P/M fraction	=	56	60	60	60 %
Wing Span	=	0.19	0.25	0.50	0.76 m
Wing Area	=	0.014	0.021	0.071	0.143 m ²
Volume	=	168	300	1700	5200 cm ³
Flight Speed	=	90	90	90	90 m/s
Range	=	50	55	72	83 km
Duration	=	590	650	800	1300 s
Glide Ratio	=	5.3	5.8	7.5	8.6
Starting Alt.	=	10	10	10	10 km

• Performance calculations based on conditions at 5 km altitude on Mars for a glider that has an analog 2gm camera

• Volume based on projected area x mean thickness x 1.2

Biomorphic Glider Deployment Concept: Larger Glider Deploy/Local Relay

Probe enters atmosphere

Parachute deployed

Heat shield released and antenna deployed (14 km).

Larger Aircraft (Large Glider) released (13 km)

Large Glider flies preset flight plan deploying the biomorphic gliders

LARGER GLIDER/AIRCRAFT

COM PORT 1

Local relay collects and transmits data to orbiter

Glider transmits data to local relay.

COM PORT 2

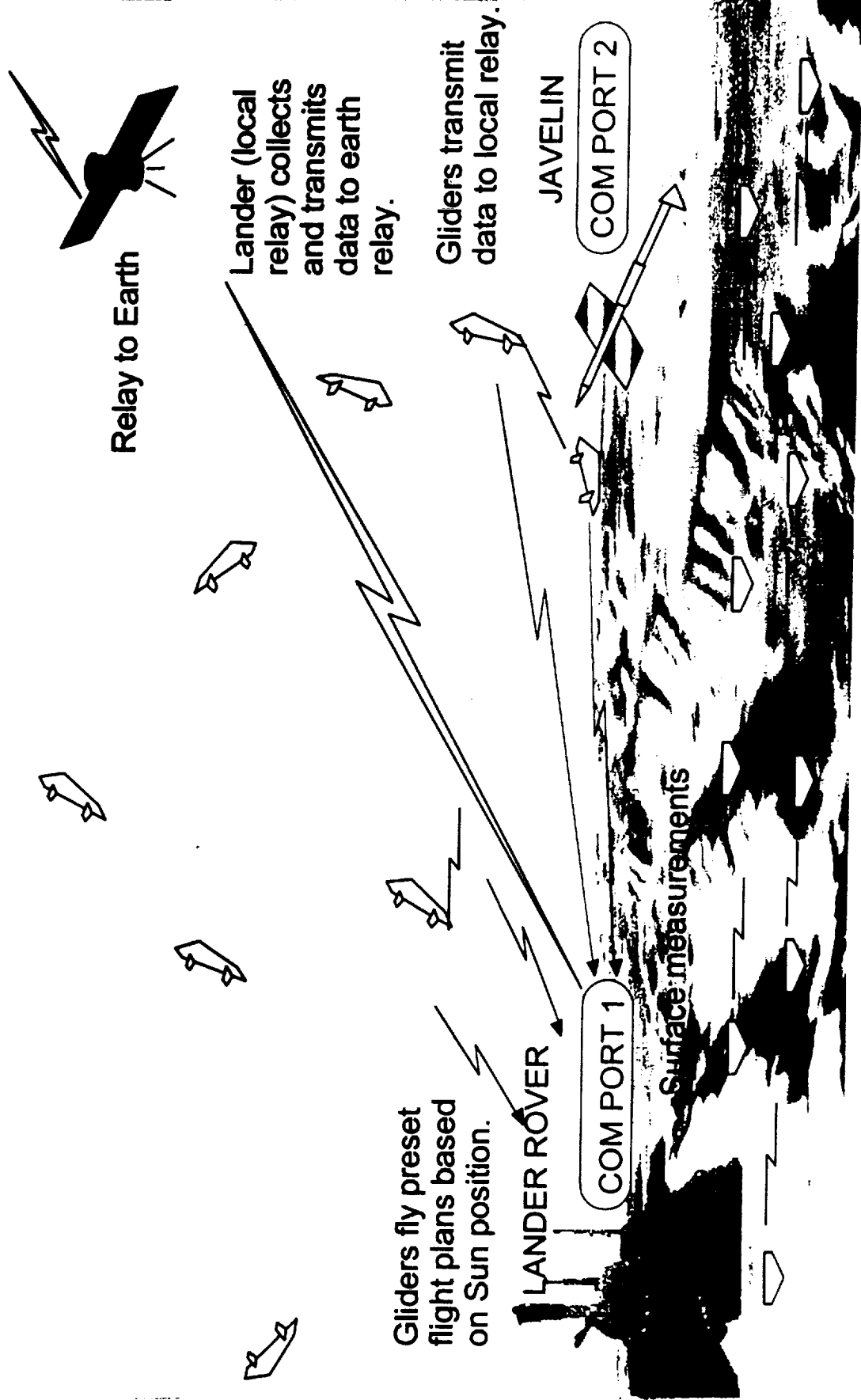
JAVELIN

Biomorphic Gliders perform in-flight maneuvers (12 km to surface)

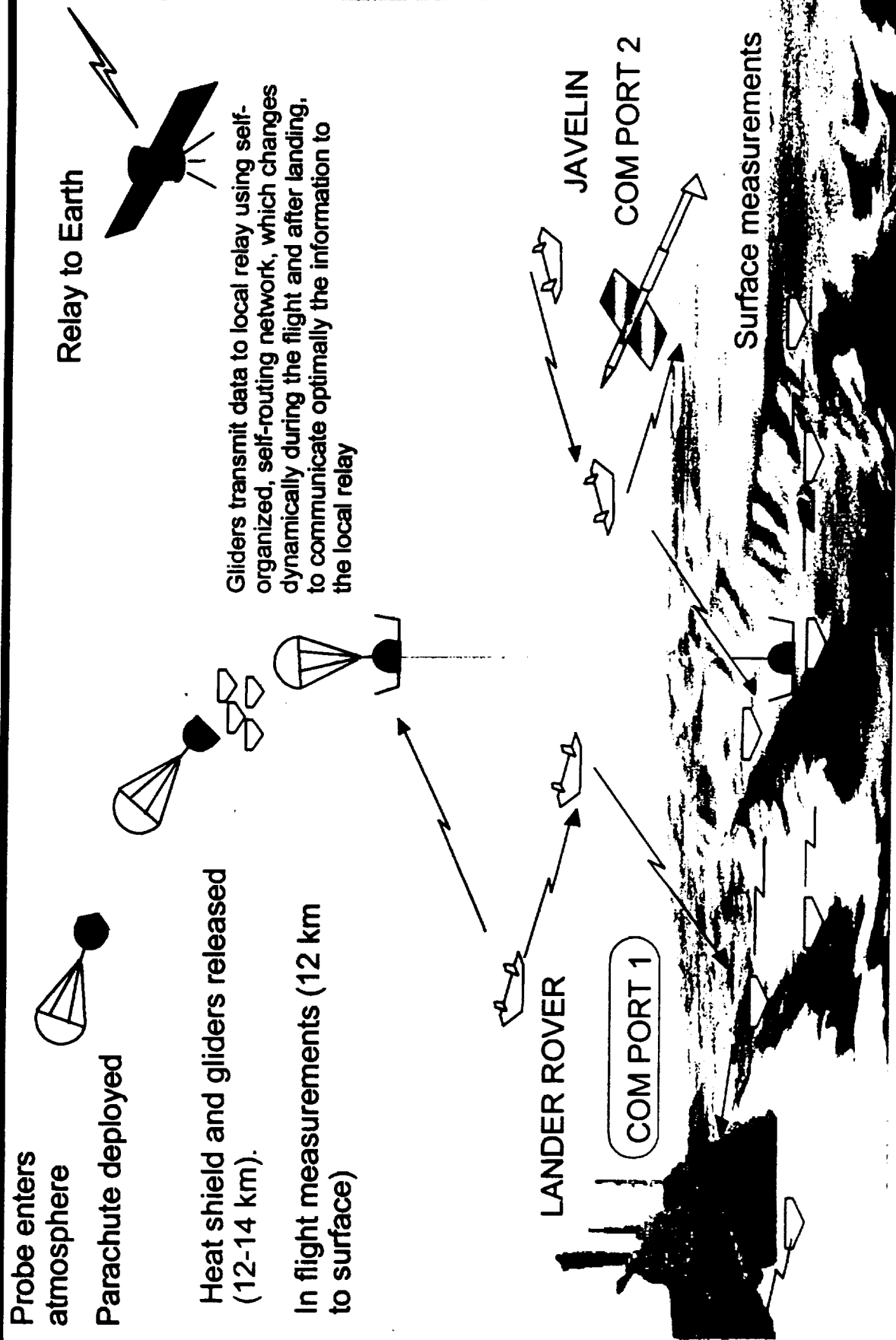
LANDER ROVER

Surface measurements

Biomorphic Glider Deployment Concept: Probe Deploy/Lander Relay



Biomorphic Glider Deployment/Telecommunication Concept





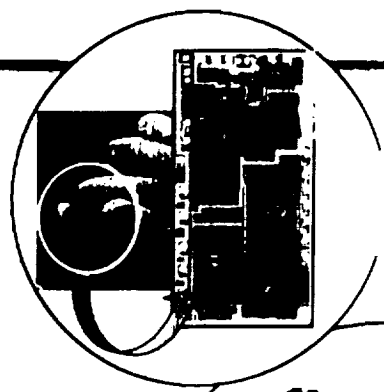
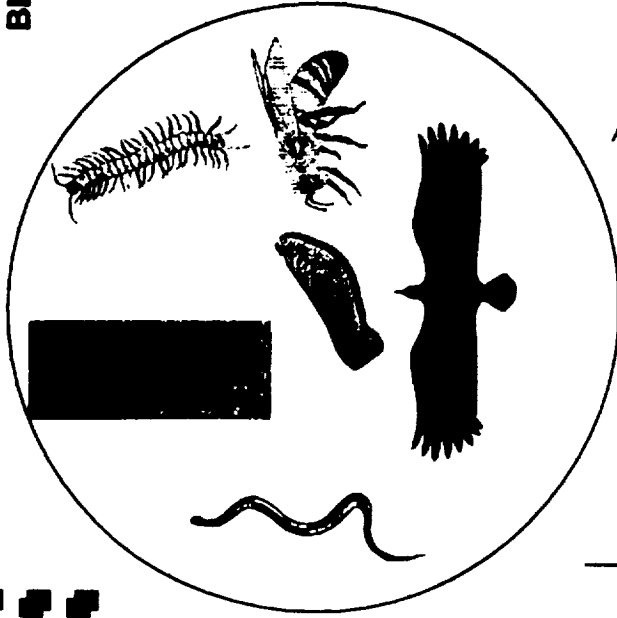
BIOMORPHIC EXPLORERS

SUMMARY & ROADMAP

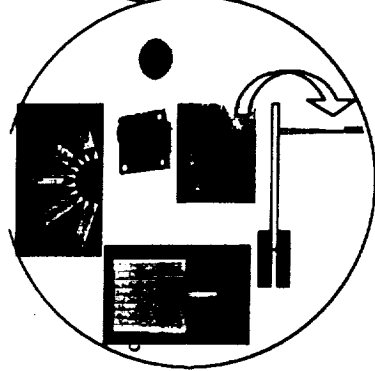
Enabling better spatial coverage and access to hard-to-reach and hazardous areas at low recurring cost



BIOMORPHIC COOPERATIVE BEHAVIOR BIOMORPHIC CONTROL ALGORITHMS



μ SENSORS



ADVANCED
MOBILITY



μ COMMUNICATION

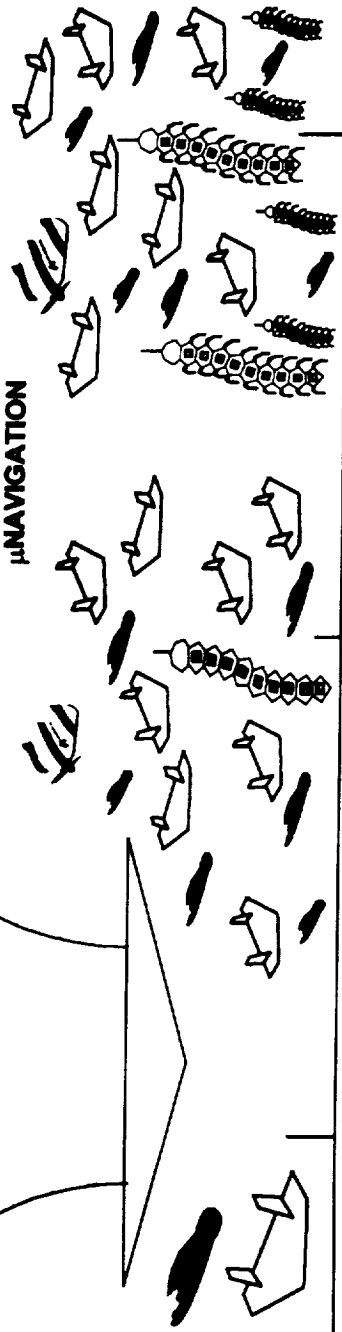
TEMPERATURE
CONTROL

μ STRUCTURE

μ POWER

μ NAVIGATION

μ COMPUTING



1997

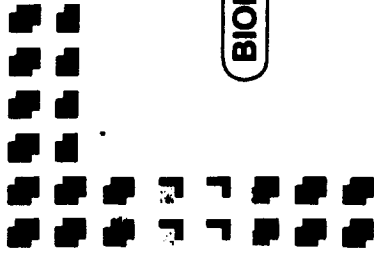
2002

2007

2012?

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COORDINATED/COOPERATIVE EXPLORATION SCENARIO

BIOMORPHIC FLYERS



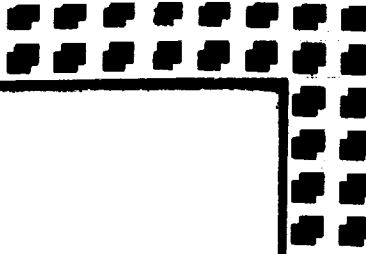
COOPERATIVE ORGANIZATION OF LANDER, ROVER, AND A VARIETY OF INEXPENSIVE BIOMORPHIC EXPLORERS WOULD ALLOW COMPREHENSIVE EXPLORATION AT LOWER COST WITH BROADER COVERAGE.





Applications

- **Distributed Aerial Measurements**
 - Ephemeral Phenomena
 - Extended Duration using Soaring
- **Delivery and lateral distribution of Agents (sensors, surface/subsurface crawlers, clean-up agents**
- **Close-up Imaging, Site Selection**
- **Meteorological Events: storm watch**
- **Reconnaissance**
- **Biological Chemical Warfare**
- **Search and Rescue etc**
- **Surveillance**
- **Jamming**



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